

STUDIES OF BLACKBODY-PUMPED LASERS

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## RECENT PROGRESS

### A. GENERAL

Laser action has been achieved in a large-scale pulsed system and meaningful experiments were carried out in the axial flow facility to understand the physics of solar-pumped lasers. Studies of the variation of laser mixture composition have been done for mixtures of  $\text{CO}_2$  and  $\text{N}_2\text{O}$  additions. Theoretical analysis and modeling of the system have also been performed based on a model including radiative pumping, diffusion and wall deactivation, and vibrational energy transfer between two optically active species. Qualitative agreement between predictions in the parameter variation and the experimental results have been obtained with  $\text{CO}$  and  $\text{N}_2\text{O}$  mixtures. This work has been published in the Journal of Quantum Electronics and is attached. Also, our experimental work on the  $\text{CO}$  system has been published at the Lasers' 87 Conference (attached herein) and an invited paper on the status of blackbody laser research was presented at this conference also.

### B. CARBON MONOXIDE STUDIES

#### i. Experimental Work

Several experimental studies were performed to quantify the properties of carbon monoxide as absorber and storage of energy in the black body pumped system. The experiments and modelling carried during the previous period (see attached publication from Lasers '87 Conference), were followed by measurements of storage capabilities during the present year. The experimental set-up was upgraded and modified to determine decay rates of the stored vibrational energy. A scheme of the set-up is shown in Fig. 1. Two cells are

positioned downstream of the pumping region, and the vibrational temperature is measured at them by the line reversal method. Tubes of various materials, surface quality, wall reflectivity, and diameter, can be used to carry the gas between cells. In this way, quantitative assessment of wall deactivation and radiation trapping effects can be made. Several measurements have been already carried out, and the preliminary results for the total decay rates are shown in Table 1. The use of Nitrogen had been proposed to improve the storage time and also the ratio of vibrational energy stored/number density of mixture. At equal vibrational temperatures, this ratio has been improved by a factor of 5 for the 20% CO + N<sub>2</sub> mixture over the equivalent Ar mixture. Also, a factor of 3 larger than the natural radiative lifetime of CO was obtained by N<sub>2</sub> addition. The other effect that was intended to prove during this preliminary measurements was the trapping of radiation by means of a high reflectivity container. A 16 mm. diameter pyrex tube was coated internally with gold at the Material Sciences Laboratory on the University of Washington campus, where a successful technique for this purpose has been developed. Using this tube to transport the mixture between the two cells a factor of 4 over the natural radiative life time was obtained for CO-Ar mixtures. This improvement can be only caused by radiation trapping. For CO-N<sub>2</sub> mixtures a time constant of 300 msec. was measured, which results from the combined effect of Treanor pumping between species and radiation trapping. Therefore, an improvement of one order of magnitude in storage time was achieved by means of these simple schemes! Further measurements of different pressures, mixture ratios, diameters, and materials, are being made. The analysis of this data will allow us to determine the importance of each component of the decay rate, those are V-T losses, radiative decay, and wall deactivation. Even longer decay times are

expected, once the various parameters are optimized as function of the data.

It is very important to know the actual vibrational temperature of CO inside the pumping cavity. This temperature has been obtained so far by extrapolation of measurements downstream of the pumping region. A new experimental set-up is being designed and built to measure the *in situ* vibrational temperature. A scheme of that set-up is shown in Fig. 2. The vibrational temperature along the cell is measured by the line reversal method. Results from this new set-up are expected soon.

## ii. Theoretical analysis and modelling

A very versatile numerical model has been developed simultaneously to the experimental work. Our code solves the rate equations of the vibrational ladder of CO under or after Blackbody pumping. The equations include radiative pumping and trapping, V-V interlevel transfer, and V-T losses. Recently, V-V transfer to N<sub>2</sub> was incorporated, and calculations for the time evolution of TV<sub>1</sub> (vibrational temperature of the first vibrationally excited level of CO) have been performed. This type of calculation provides very good analytical means for the data obtained in the experiments. Also, this code constitutes an excellent tool for evaluation of possible laser schemes, either *in situ* or by energy transfer. A large number of runs for different mixtures, pressures, gas temperatures and BB temperatures were performed and submitted recently to NASA at the request of Dr. R. De Young. Steady state solutions for the populations of up to 40 levels, and some time evolution solutions, were calculated. This data would allow to analyze possible V-V or V-E transfer laser systems, were CO constitutes the pumping energy absorber/storage. The V-E transfer terms will be incorporated into the code to

evaluate more accurately these systems. Since a solver for very stiff system of equations is applied in the code, very different and fast rates inside the equations are possible.

### C. CARBON DIOXIDE SCALING STUDIES

Successful construction of a new rectangular laser tube with sapphire windows has been accomplished for the CO<sub>2</sub> blackbody laser scaling studies. Lasing action using this system shows much higher output power than the previous apparatus using a quartz tube. A typical laser output pulse which decays steadily as the foil temperature drops is shown in fig. 3. An output power of 640 mw has been achieved by using 30 torr of single isotope CO<sub>2</sub> laser gas mixture (15% CO<sub>2</sub>, 42.5% Ar, 42.5% He) at 250°K gas temperature.

The scaling effects of blackbody temperature, gas temperature, gas mixture and laser mode volume have been studied using this system and is described in the following:

(1) Blackbody temperature effect: It is obvious that blackbody source pumping power can be increased by raising its temperature as shown in fig. 4; therefore the laser gain and output power can be increased. The computed small signal gain for different blackbody temperature and gas temp is shown on fig. 5. As shown in the graph, the gain can be tripled by increasing the blackbody temperature from 1500°K to 2500°K. The measured output power at different blackbody temperature is shown on fig. 6: in this picture we see a threshold of about 1300°K for the laser mixture so indicated on the figure. The laser power increases smoothly up to 2650°K at which the laser power is 220 mw.

(2) Laser gas temperature effect: There are several advantages in reducing the laser gas temperature. The optical line width is inverse proportional to the square

root of temperature in pressure broadening range. Therefore, the lower the gas temperature, the higher the absorbed pumping power. Due to the low gain of the blackbody laser system, reducing the population density of the lower laser level by lowering the laser gas temperature is a very effective way to increase the laser gain. Fig. 5 also shows the computed small signal gain at different gas temperatures. It shows the gain can be doubled by reducing the gas temperature from 300°K to 200°K. The measured laser power at different gas temperature and pressure is shown on fig. 7. Due to the increased laser gain at lower gas temperature, the laser output power can be achieved 640 mw at a optimum pressure of 30 torr.

(3) Laser gas mixture: Several different laser gas compositions have been tested by varying the concentration of CO<sub>2</sub>, Ar, and He. The results indicate that the best gas composition at 300°K gas temperature is 15% CO<sub>2</sub>, 42.5% He, and 42.5% Ar. There is evidence that higher CO<sub>2</sub> concentration can be used at lower gas temperature based on quartz tube's experiment.

(4) Laser mode volume: In order to increase the laser mode volume and have better utilization of the pumping energy which is deposited into the laser tube, we have used a waveguide laser cavity due to its larger mode volume and low cavity losses as shown in table II. A waveguide laser cavity using sapphire plates and copper side walls has been constructed and tested. A comparison of measured output power between waveguide laser and conventional laser is shown in fig. 8. We can see there is about 40% increase in laser output power by using wave guide structure. Nevertheless, the optimum gas pressure for waveguide laser is decreased.

The wave guide mode has been measured at different locations as shown on fig. 9. Because of the instability of the laser pulse, it is hard to determine whether it is single mode or multi-mode from these measurements. Nevertheless, the beams divergence can be estimated by these measurements: They are about 2 mrad in x-direction and 3 mrad in y-direction. The mode polarization has been measured by detecting the reflected beam from a Brewster window.

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TABLE I

## DECAY RATES FOR VIBRATIONALLY EXCITED CARBON MONOXIDE MIXTURES

MIXTURE	PRESSURE (TORR)	TRANSPORTING TUBE DIAMETER (MM)	MATERIAL	SPEED (CM/SEC)	$\tau$ (MSEC.) $\pm 10\%$
10% CO + Ar	200	8	pyrex	270	31
20% CO + Ar	200	8	"	270	30.5
20% CO + Ar	200	4	"	540	24.5
20% CO + N <sub>2</sub>	400	8	"	270	76
25% CO + N <sub>2</sub>	400	8	"	270	86
30% CO + N <sub>2</sub>	400	8	"	270	75
10% CO + Ar	400	16	internally gold coated pyrex	67.5	102
20% CO + Ar	400	16	"	135	93
30% CO + Ar	400	16	"	135	125
20% CO + N <sub>2</sub>	400	16	"	135	297



TABLE II

COMPARISON OF MODE VOLUME & CAVITY LOSS  
BETWEEN GAUSSIAN & SLAB WAVEGUIDE MODE

mode type	mode volume (cm <sup>3</sup> )	cavity loss ( % )
TEM <sub>00</sub>	24	0.1
TEM <sub>01</sub>	32	2
TEM <sub>02</sub>	37	10
TE <sub>1</sub>	150	0.012
TE <sub>2</sub>	150	0.06
TE <sub>3</sub>	150	0.09
TE <sub>4</sub>	150	0.18

# Gaussian mode is computed for confocal resonator

(cavity size: 1cm x 1cm x 300cm)

# Waveguide, 1cm x 300cm, plane mirror coupling, 5mm spacing,  
500m bending radius.

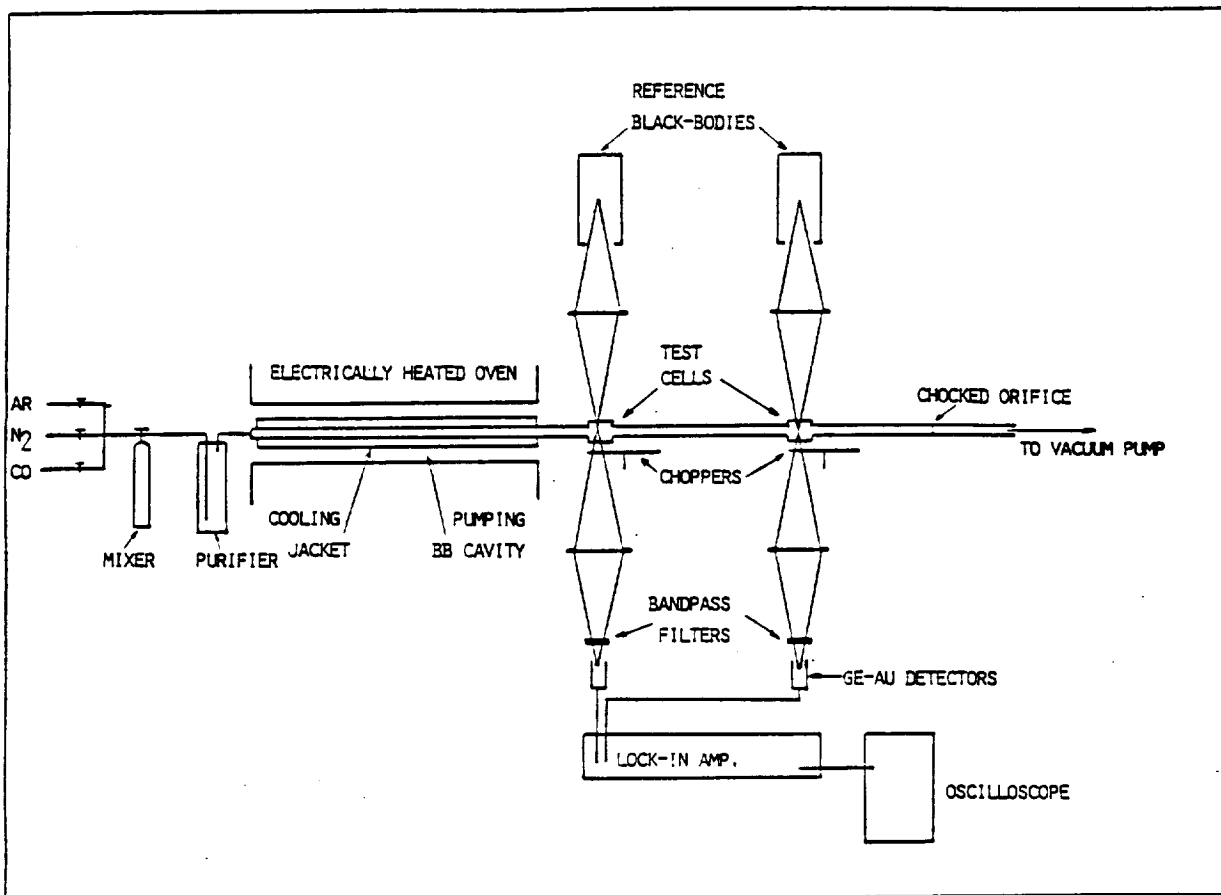


Fig. 1. Experimental set-up for decay rate measurement.

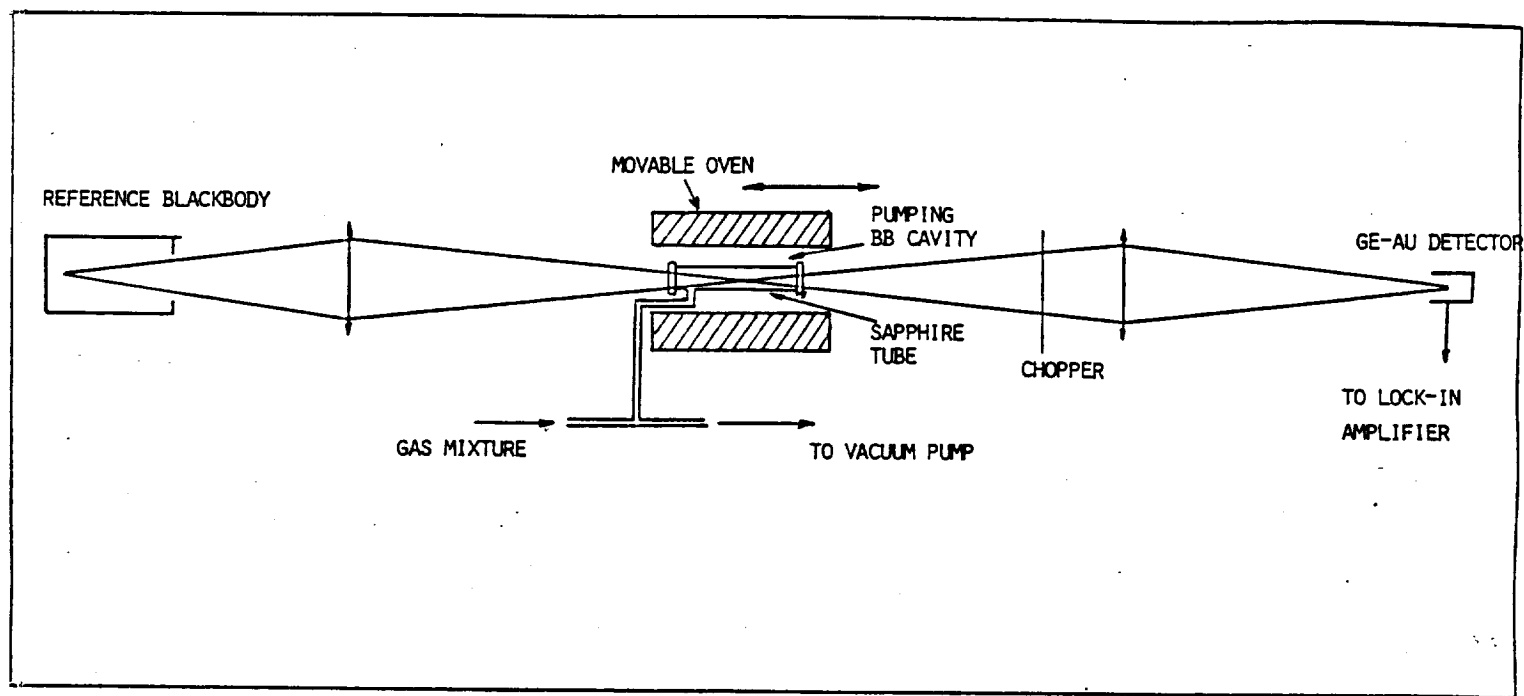


Fig. 2 Experimental set-up for "in-situ" vibrational temperature measurements.

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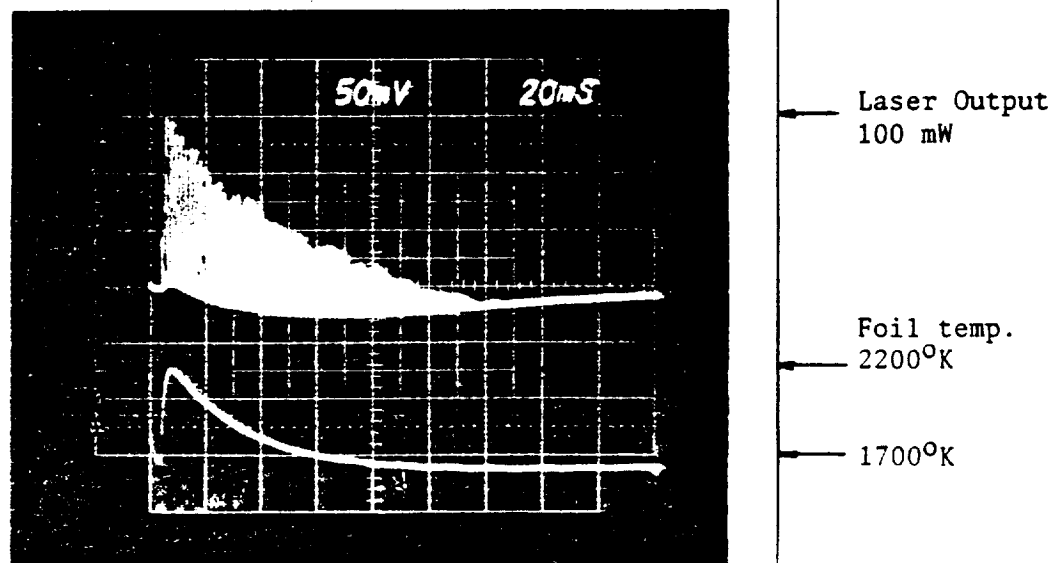


Fig. 3 Typical laser output vs time

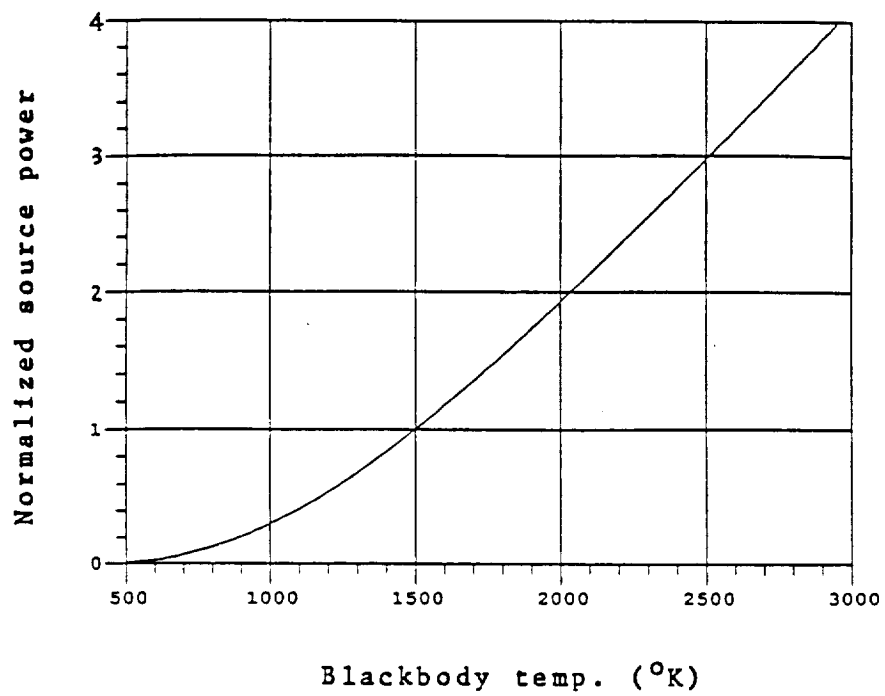


Fig. 4. Source Power vs. Blackbody Temperature

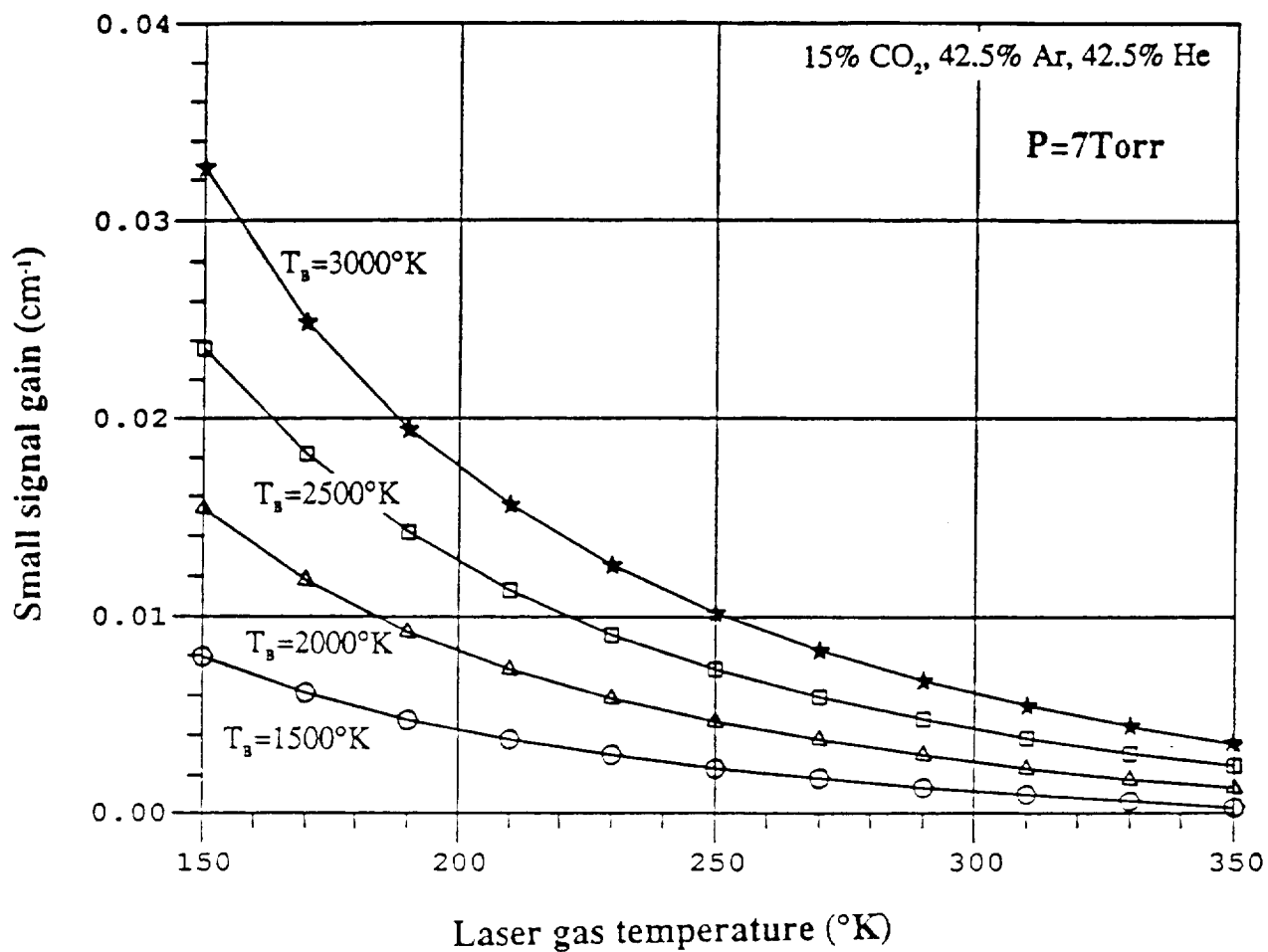
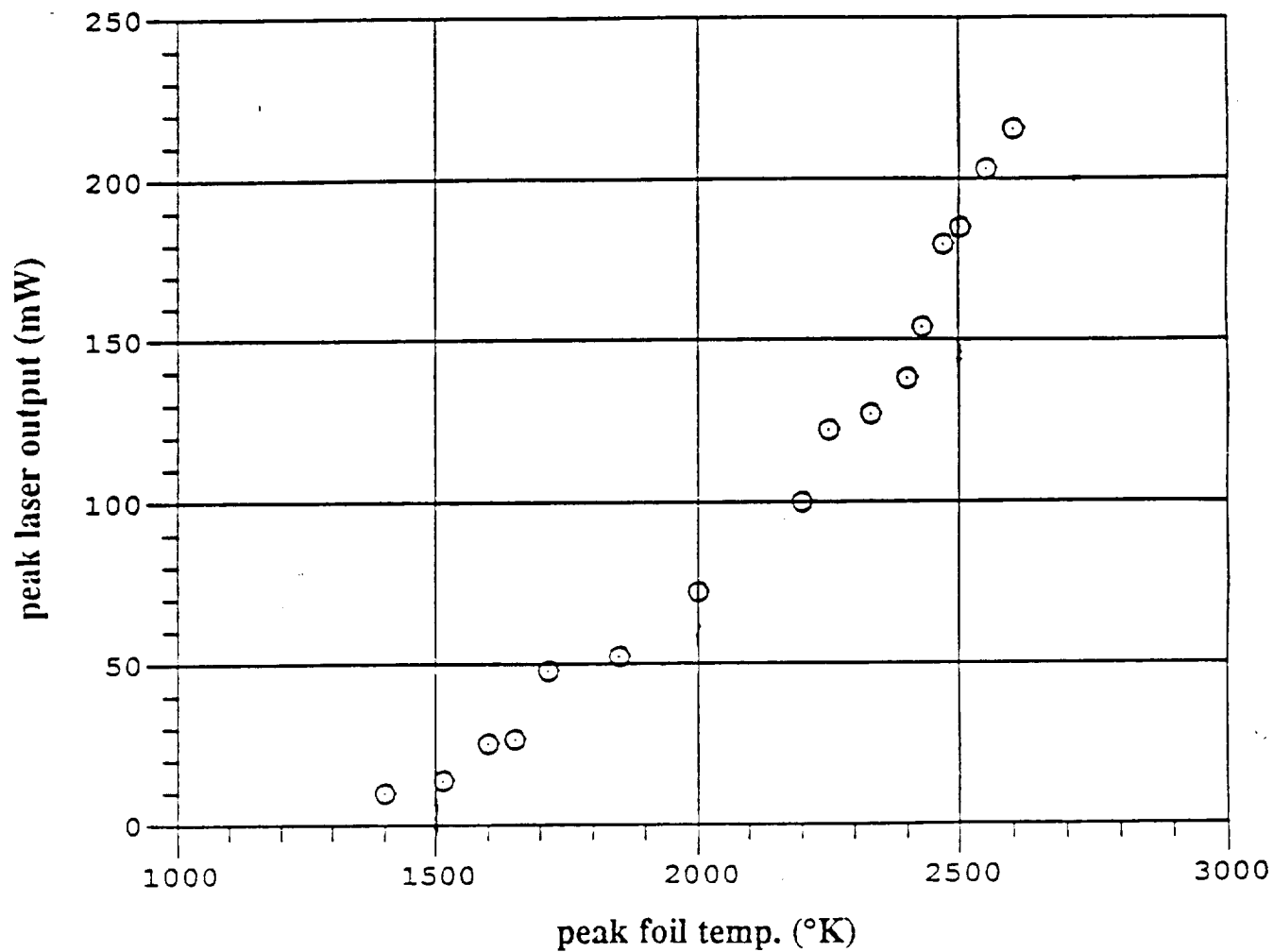
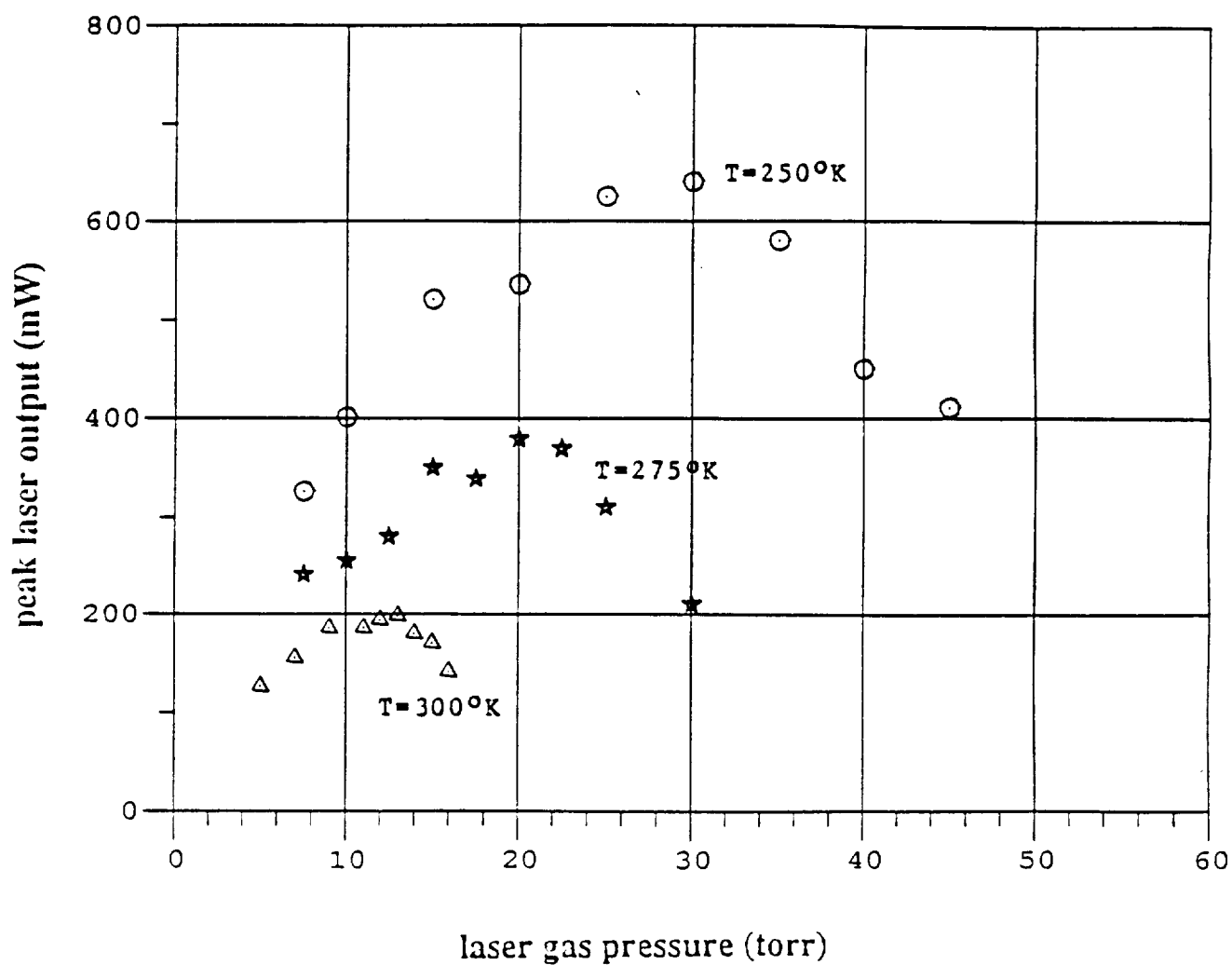


Fig. 5. Calculated Small Signal Gain vs. Temperature.



Laser gas mixture: 15% CO<sub>2</sub>, 42.5% Ar, 42.5% He  
Gas pressure: 8 torr      Laser gas temp: 300°K  
Tube size: 9mm x 10mm      Gain length: 90cm  
Output coupler: 5%

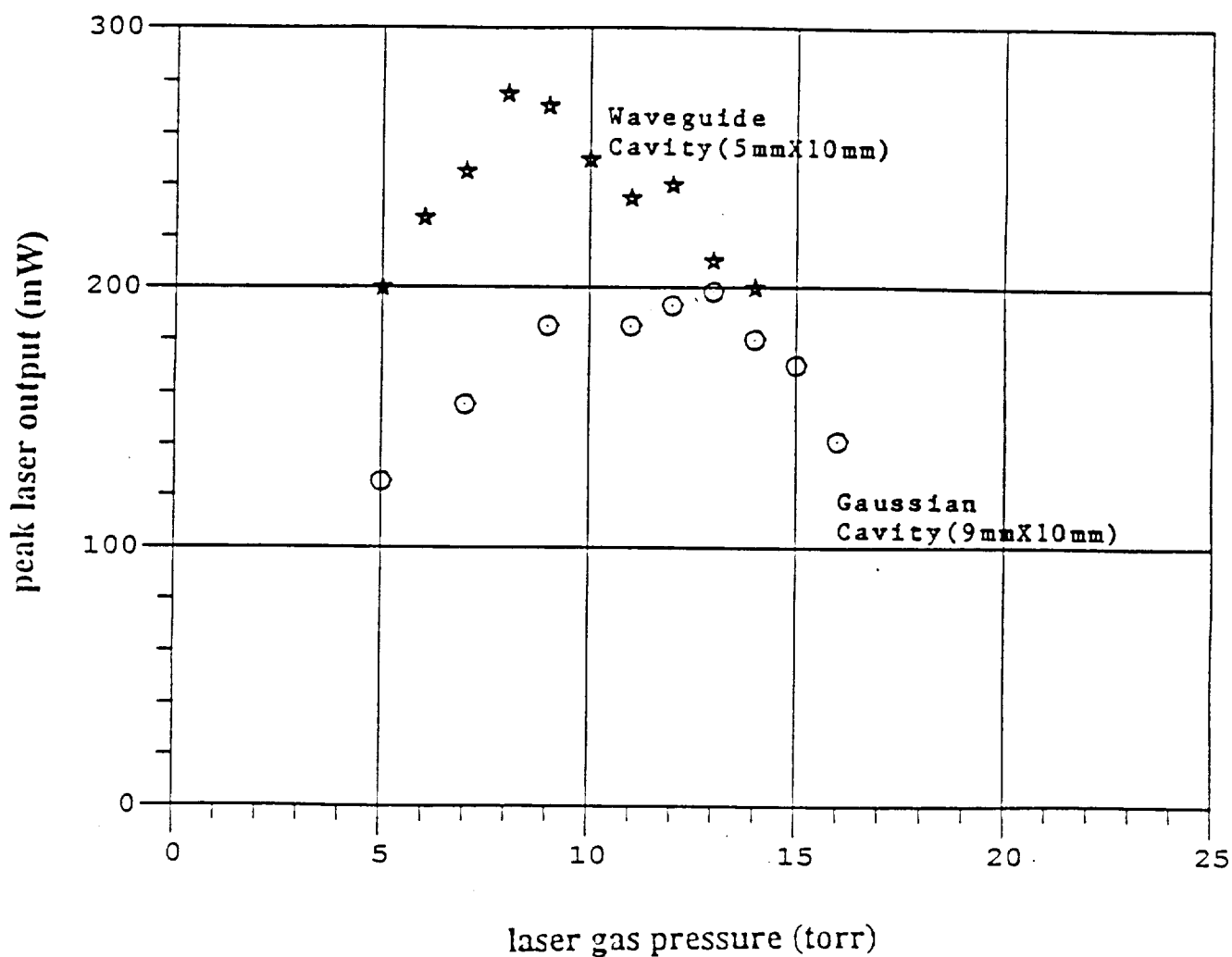
Fig. 6. Laser Output Power vs. Tantalum Temperature.



Laser gas mixture: 15%  $\text{CO}_2$ , 42.5% Ar, 42.5% He  
 Foil temperature:  $2500^{\circ}\text{K}$  Output coupler: 5%  
 cavity size: 0.9cm x 1.0cm gain length: 90cm

Fig. 7. Laser Power vs. Gas Pressure & Gas Temperature.





Laser gas mixture: 15% CO<sub>2</sub>, 42.5% Ar, 42.5% He  
 Foil temperature: 2500°K      Output coupler: 5%  
    gain length: 90cm

Fig. 8. Output Power for Waveguide & Gaussian Cavities.

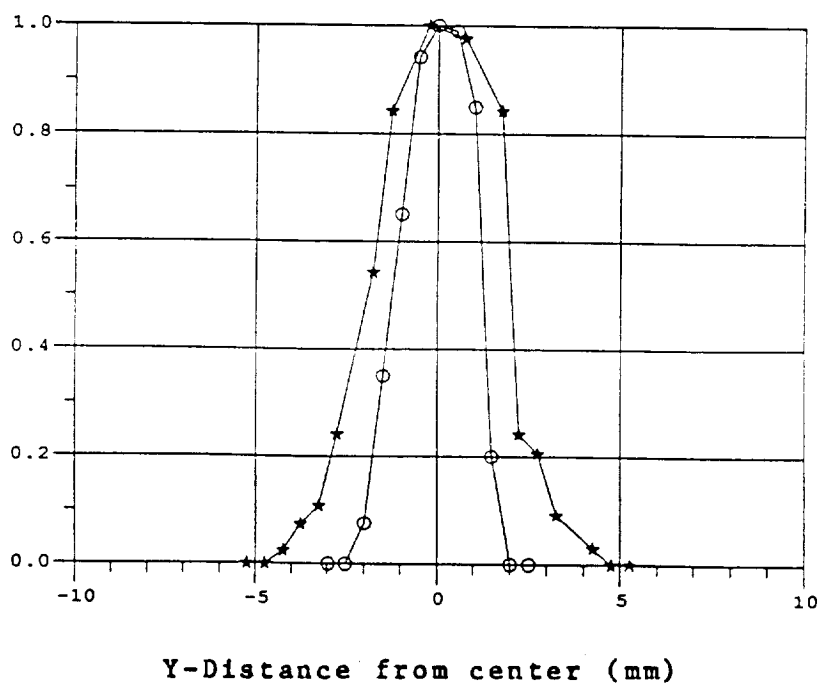
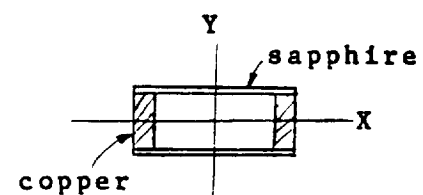
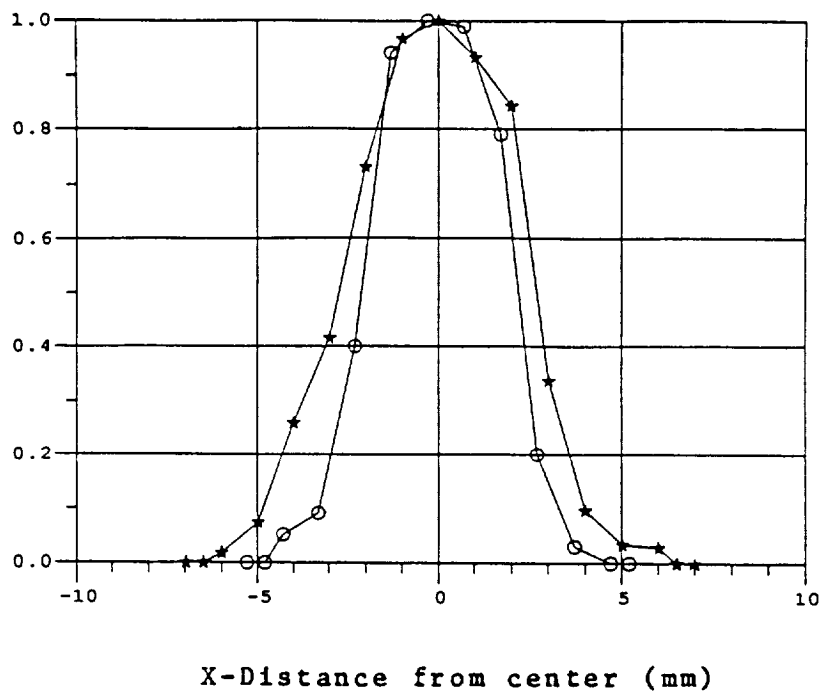


Fig. 9. Mode Shapes of Output Laser Beam.